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Decision Support for Battlefield Planning

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14. ABSTRACT *(Maximum 200 words)*:

As part of a research program investigating decision support capabilities for battlefield planning, an examination was made of developmental systems in each of five principal elements of Army C21: maneuver control, fire support, air defense, intelligence and electronic warfare, and combat support services. The systems described generally fall into two categories (with some overlap): (1) decision support systems that attempt to capture automatic specific decision processes, usually employing advanced technologies such as artificial intelligence; and (2) decision aids that attempt to enhance human cognition in command decision making, usually based on psychological research findings. These efforts appear to be mainly driven by technology, rather than being based on systematic study of operational requirements, and there is little evidence of their operational use. Another type of support, not reviewed, takes the form of application programs that process data already available in management information systems; these are being built into C21 systems by the systems developers, and are therefore likely to find operational use. Increased emphasis on studying command decision making requirements is recommended.

15. SUBJECT TERMS

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DECISION SUPPORT FOR BATTLEFIELD PLANNING

EXECUTIVE SUMMARY

Findings:

Overall, our review of the development of decision-support capabilities for Army C^2I decision making revealed three basic trends. First, developers of C^2I systems, such as the MCS and AFATDS, are also pursuing development of 'application programs' to provide automated analytic support to commanders and analysts. Although only briefly discussed in this report, there appears to be a considerable amount of this type of work ongoing in corporations building C^2I systems. These decision-support application programs are, for, the most part, not based on either advanced technologies (such as AI) or psychological studies of human decision making. Rather, they reflect the C^2I system developers' thoughts on useful application programs. Despite this, the fact that these application programs are being developed in concert with the development of to-be-fielded C^2I systems, suggests that they are likely to see some operational use.

The second trend involves research in the development of decision-support systems that will apply algorithms, based on advanced technologies such as AI, to automatic data analysis and advice generation. Nearly all of the work in the development of AI systems for C^2 decision support fall into this category. Virtually all of this work is technology-driven in that its principal objective is to apply a specific technology (viz., AI) rather than to solve a problem that has been clearly defined by a systematic investigation of operational requirements.

The third trend involves the development of decision aids designed to directly support a commander's or intelligence analyst's decision processes, rather than automatically generating recommended decisions. These aids are based on general psychological research in human decision making and are often computationally very simple. They are not generally based on empirical investigations of the decision and judgment processes used by commanders and intelligence analysts. Consequently, despite their psychological orientation, they could still be classified as technology-push efforts.

Overall, it appears that, despite numerous ongoing attempts to develop computer-based systems to support command decision making, relatively little emphasis has been placed on investigating the specific command decision processes these systems are designed to support.

In order to properly evaluate the effectiveness of these systems, it seems essential to obtain baseline empirical data on unaided command decision processes and performance; furthermore, if such data were obtained early and systematically, they could provide rational guidance for future DSS and DA developments, viz., by specifying critical operational needs.

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INTRODUCTION

This paper reviews efforts in the development of decision aids relevant to the problem of planning the tactical activities of ground forces. The paper was prepared in support of the Evolutionary Decision Making research effort, which is sponsored by the Basic Research Office of the Army Research Institute. The overall goals of the research effort are to:

1) investigate the decision-making procedures utilized by military planners during the evolving process of battlefield planning and wargaming; and, based on this investigation, to

2) identify and evaluate decision-aiding concepts and training innovations for the planning and wargaming process.

The goal of this paper is to review and characterize previous and ongoing efforts to develop decision aids for battlefield planning and wargaming. In particular we are interested in:

1) the technological approach to decision support being employed by decision aid developers; and

2) the reasons that guided both the selection of the aids to be developed and the technical approach to decision support.

This paper is not a comprehensive survey of all past and ongoing efforts in computer systems for battlefield decision support. Such a survey is well beyond the scope of this effort. Rather, the focus is on developing a general understanding of the types of systems that are being developed and why they are being developed.

The first section provides a brief discussion of the terms 'decision aid' and 'decision support system' and their meanings in a command, control and intelligence (C^2I) system context. The succeeding sections review the efforts to provide computer-based support of battlefield C^2I decision processes.

DECISION AID VS. DECISION SUPPORT SYSTEM: WHAT IS THE DIFFERENCE?

In the R&D community, the terms 'decision aid' and 'decision support system' are often used to indicate some type of device, usually computer-based, that promotes better and/or faster decision making. Today, common usage often interchanges these terms, and generally allows them to refer to any type of device that augments decision making, ranging from manual cue cards to graphic display systems to sophisticated expert systems.

Common usage notwithstanding, the terms 'decision aid' and 'decision support system' have distinctly different etymologies that, historically, reflected two different approaches to decision support. (The term "decision support" is used herein in the generic sense. Computer-based systems for decision support would include both "decision aids" and "decision support systems".) The differences between these two approaches are discussed below. The relevance of this digression will become apparent at the end of this section.

The concept of a 'decision support system' (DSS) evolved from work in the development of database systems stemming from the computer and information sciences. When first developed, database management systems (DBMS) were initially designed to handle, organize, and provide easy access to the large quantities of data that a government or commercial organization must handle. With the advent of DBMSs, it became clear to many developers that much of the information needed by senior managers in day-to-day decision making would be resident in the DBMSs that were being developed and could be made easily available to these managers. Consequently, the concept of a management information system (MIS) emerged. The MIS would be an on-line system that would provide a manager with a number of tabular and graphic summaries of the status and activities of an organization, with perhaps some simple analytic support. With an MIS a manager could effectively monitor the status of the organization and identify significant changes or trends. With the advent of MISs, however, it also became clear that another enhancement was possible. Specifically, in addition to simply providing the manager with a summary of a dynamic database, it was also possible to perform some automated analysis of those data to provide some analytic conclusions or advice on the interpretation and meaning of the summary data (e.g., business forecasts). The concept of a decision support system emerged as an on-line system that would provide support to complex decision making by performing automated analyses to enhance a decision maker's ability to monitor, interpret and/or utilize a database. While developers of DSSs were concerned with human decision processing and other issues in the design of a DSS, the principal objective of a DSS appears to have been enhanced data utilization (e.g., Keen and Scott Morton, 1978).

The concept of a 'decision aid' (DA) grew out of research in normative and psychological decision theory. Normative decision theory addresses the mathematical basis of decision making, and provides formal models for how quantitative judgments should be combined in the judgment and decision-making process. Probability/Bayesian theorists, for instance, specify how probability judgments should be modified in the light of new evidence, while utility theory provides a basis for evaluating options on the basis of judgments of outcome utility and event probabilities. Psychological decision theory, on the other hand, addresses the realities of human judgment and decision-making behavior. Psychological models of human decision making focus both on how people make decisions as well as on how human decision processes may diverge from normative models. It is this latter issue, divergence from normative models, that appears to have led to the concept of a DA. A decision aid was initially thought of as a computer-based device that would execute a normative decision model against a user's perception of a problem. That is, the user would enter 'simple' judgments about the relative utility of different outcomes, or conditional probabilities of an event, and the decision aid would execute a normative decision model that would aggregate these independent judgments into an overall assessment of probability, utility or expected utility of alternative choices.

For instance, one of the earliest concepts for a decision aid was to use Bayes' Theorem to calculate the probability of a hypothesis. The need for such an aid is based on the observation that people are overly conservative in revising probability estimates on the basis of new information. The Bayesian aid would accept several probability inputs such as the user's assessment of the probability that an event would occur given a hypothesis was true, and the aid, in turn, would calculate the revised probability that the hypothesis was true given that the event was observed.

A decision aid, therefore, was initially conceived of as a computer-based device that would provide automated analytic support of a user's judgmental process, and, in particular, would automatically combine a user's elementary judgments into overall probability and utility judgment. That is, the goal of a decision aid would be enhanced decision processing based on user-generated assessments.

Historically, therefore, the focus of a DSS was enhanced data utilization, while the focus of a DA was enhanced decision processing. Although the distinction between these two terms has dissipated over time, the distinction between enhanced data utilization vs. enhanced decision processing remains an important one. In particular, in the Army C^2I arena there is a considerable amount of work ongoing or anticipated in enhanced data utilization, but relatively little work in enhanced decision processing. A discussion of some of these efforts in provided in the next section.

DECISION SUPPORT IN BATTLEFIELD PLANNING

Recent discussions of Army C^2I generally present the Army C^2I system as composed of five principal elements. As shown in Figure 1, these are:

Maneuver Control,
Fire Support,
Air Defense,
Intelligence and Electronic Warfare, and
Combat Support Services.

The Army is presently engaged in a significant upgrade of its C^2I system, with the intent that a single system would be procured for each of the above five elements. Each of these systems will provide for communication and data-sharing among the various nodes within each of these elements, as well as some data-sharing and communication between elements. Each of these systems, in effect, represents a distributed database capability with manager (commander) interface support. Consequently, from the perspective of the discussion in Section 2.0, the Army is presently engaged in the development of five separate, but interrelated, MISs (Intelligence and Electronic Warfare is a partial exception to be discussed later).

Given that the Army is already engaged in MIS development, it is only natural that the Army and the developers of these systems began to think about enhancements to the basic MIS capabilities. Many of these enhancements come in the form of 'application programs' that automatically provide commanders with additional analyses based on the data made available via the MIS. With the addition of these application programs, the Army is moving into the DSS arena.

Independent of these application-programming activities, the Army has also pursued research and development on alternative forms of decision support. This work has come in two forms. The first involves efforts to capture and, in part, automate the specific decision processes and heuristics that commanders utilize. Much of this work has come from the artificial-intelligence (AI) initiatives in this area and is focused on providing commanders with AI-based advisory systems. As discussed in

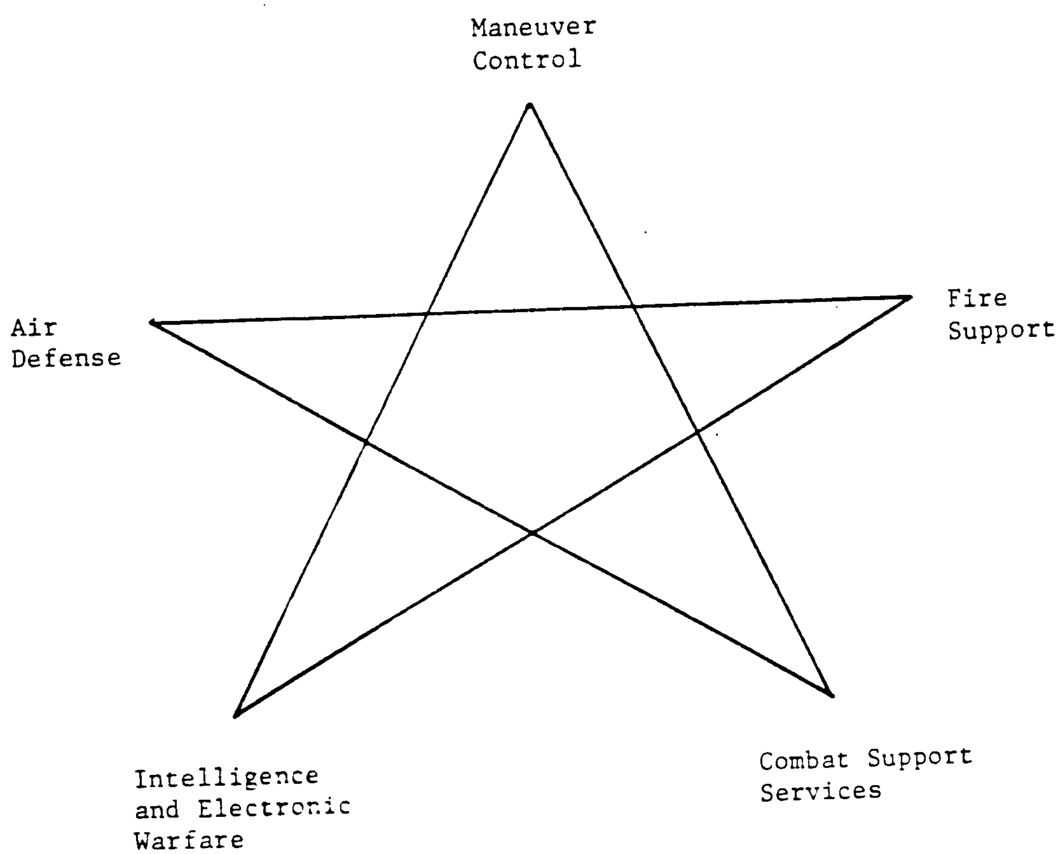

Figure 1. Elements of the Army C^2I System.

Lehner (1987), most of these systems are designed to provide an "intelligent interface" to an external data source, and therefore would be classed as DSSs.

The second comes from the work of psychology-oriented researchers who are specifically interested in the cognitive processes of command decision making, as well as the development of procedures to directly assist training or implementation of these processes, i.e., decision aids. This latter approach is distinguished by its lack of commitment to specific technologies (or even to the use of advanced technologies).

In sum, there appear to be three different types of computer-based decision-support capabilities being developed for Army commanders: application-program DSSs, advanced-technology DSSs, and psychology-based DAs. The remainder of this section examines each of the five elements in the Army C^2I systems and discusses DSS and DA development activities in each of these areas. Since the focus of the Evolutionary Decision Making effort is on understanding and supporting the human decision processes involved in planning and wargaming, our principal interest is in psychology-based DAs and the advanced-technology DSSs, rather than on DSS application programs. In addition, it should be noted that acquiring information on application programs is often difficult, since they often represent the in-house proprietary work of a contractor trying to enhance the contractor's position in a competitive procurement for a C^2I system.

Maneuver Planning and Control

Maneuver planning is the determination of how ground forces should maneuver and engage. Maneuver control is the ongoing management and control of the maneuvers of ground units. The Army is presently in the process of incrementally procuring a system called the maneuver control system (MCS). The MCS is a distributed database system that will provide battlefield commanders with real-time combat data (e.g., troop maneuvers, battlefield conditions) principally as a series of graphic displays. The MCS should provide the basic data a commander requires to make ongoing maneuver control decisions, and is therefore essentially an MIS for maneuver control decision making.

Maneuver control involves real-time decision making on the maneuver activities of ground forces. Maneuver planning involves longer-term considerations where plans for possible maneuvers are examined for a period ranging from hours to days, depending on the echelon. Whereas maneuver control is a very data-directed process, maneuver planning, particularly at higher echelons, is much less data-dependent. The 'situations' that a planner faces are those that are hypothesized to result from the execution of a proposed maneuver against possible maneuvers hypothesized for the enemy.

Provided below is a brief description of five systems designed to support maneuver planning decision processes. BRIGADE PLANNER is essentially a DSS application program that is designed to augment the capabilities of the MCS. The other four systems (TACVAL, TACPLAN, ARES, and ALBM) are designed for division- and corps-level planners, and focus more directly on either emulating or supporting the commanders' decision processes.

Brigade Planner

BRIGADE PLANNER is an in-house effort ongoing at the U.S. Army TRADOC Analysis Center to develop a computer-assisted tactical planning tool for brigade commanders to plan combat operations (Diaz and Smith, 1986). BRIGADE PLANNER is designed to provide the commander with a series of quantitative tools for evaluating good fighting positions and evaluating likely combat outcomes, as well as tools to speed up/automate the process of generating operational orders.

The technical approach for designing and developing BRIGADE PLANNER relies heavily on the exploitation of existing analytic models for terrain and force/combat analysis. These models, enhanced with some additional models and software, will form the basis of BRIGADE PLANNER.

BRIGADE PLANNER is scheduled to undergo initial field testing in 1987. If successful, it will be incorporated into the maneuver-control system.

This effort was requested and is being sponsored by the U.S. Army Training and Doctrine Command, at the instigation of a number of Army commanders with brigade command experience work.

TACVAL (TACtical eVALuation)

TACVAL is a decision aid based on normative decision theory. It is designed to assist in the evaluation of alternative tactical courses of actions (COAs) by allowing a decision maker to perform a hierarchical multiattribute utility (MAU) analysis of different COAs. TACVAL provides the user with a hierarchical MAU structure, and the user completes the model by providing the weights, options, and scores for each MAU factor on each option. TACVAL then presents to the user a numerical ranking of the optional COAs. This aid also uses MAU hierarchies to evaluate potential concepts of operation. More recently, a similar aid called CONSCREEN was delivered to the Army War College.

TACVAL and CONSCREEN are attempts to apply formal decision-theory techniques to a military planning problem. Operational applications of such decision-analytic aids in military planning are rare, and are usually resisted because of the large number of explicit subjective judgments required. They can be effective as training tools insofar as they enhance understanding of the implicit judgmental processes required.

TACPLAN (TACtical PLANner)

Within the decision-support systems arena, relatively few systems have been built that are designed to support senior command-level decision processes. This is, in part, because effective decision making at senior levels usually involves a decision process that calls upon the decision maker's broad experience and knowledge base. Artificial intelligence (AI) systems, for instance, are usually limited to domains where the knowledge required for problem solving is both well-defined and limited in scope. A similar constraint applies to aids that are based on operations research (OR) techniques, which are limited to the range of factors that can be represented in mathematical formulations of operations research models.

Given the present state of technologies such as AI, OR, and decision theory (DT), decision support systems that can provide significant support to senior decision makers are probably limited to the role of a local advisor or critic. That is, while the DSS may not be able to replace a senior commander's extensive experience and knowledge base to generate decision options, it may be in a position to evaluate important options from the perspective of limited subproblems.

In order to build a system of this type, one design problem that must be addressed is that of communication with the decision maker. Since it is still the decision maker's role to control option generation, the DSS must have embedded within it a simple and natural mechanism for transcribing and representing user-generated options. This may be quite difficult for decision problems such as planning maneuver campaigns, where an option may be a complete concept of operations or a plan that involves many factors, sequencing considerations, levels of detail, etc. that human planners may find too time-consuming to make explicit during the planning process.

One example of a system that adopts an "advice for limited subproblems" approach is TACPLAN. It is a prototype aid, under development, which is designed to support Army Corps staff personnel in the formulation of concepts of operations (Andriole, 1986). TACPLAN is composed of three major conceptual components: (1) a video disc-based user interface for map displays; (2) several analytical modules; and (3) a variety of knowledge bases of tactical planning and facts.

TACPLAN permits planners to enter their guidance and mission definition and then elicits judgments about aspects of the planning process (area characteristics assessments, relative combat power, etc.). TACPLAN checks these judgments against criteria defined in the various rule bases relevant to these judgments. If TACPLAN fires rules that lead to a disagreement with the planner, it will present the planner with the violated rule and offer advice (which may be rejected) to the planner about how to resolve the conflict.

The video disc-based interface permits planners to annotate directly onto a map display by drawing candidate courses of action. TACPLAN then reads the annotation, accesses the relevant knowledge bases, and reports back to the planner about problems and opportunities presented by the candidate course of action.

A related system, called INTACVAL, is also being developed. INTACVAL will essentially function as a 'fast-time simulator' that will provide informative feedback on the possible consequences of a proposed maneuver plan.

Unlike most of the decision-aid development efforts described herein, the TACPLAN effort involved an initial empirical investigation of the decision processes involved in maneuver planning. In particular, video tapes of problem-solving sessions with officers of different experience levels were collected. In the procedure, a facilitator was present who would frequently interject questions into the decision process and ask the planners about various aspects of the planning and reasoning process. The technological approach embedded within TACPLAN was selected as a result of a review of these videotaped sessions.

<u>ARES (Artificial Intelligence Research)</u>

The ARES project is an effort ongoing at the U.S. Army Communications-Electronics Command (CECOM) to explore the application of AI methods and tools to problems in maneuver planning and control. The focus of this work is on the development of two decision aids: one for planning future operations (maneuver planning proper) and the second for monitoring and controlling ongoing operations (maneuver control).

At the time of this writing, this program of research is still relatively new. Most of the work to date has been on the problem of defining appropriate computer-based representations of the elements of the battlefield, and not on the maneuver planning and control decision problems per se.

ALBM (AirLand Battle Management)

The ALBM program is a part of the DARPA Strategic Computing Program (SCP). The overall goal of the SCP is to promote the advancement and utilization of AI technology by funding the development of several types of application systems. These systems include autonomous robot vehicles, decision-aiding software for pilots (i.e., a pilot's associate), and battle management systems. AirLand Battle Management is one of three battle management problems DARPA has targeted for AI application.

The specific focus of the AirLand Battle Management program is to develop a set of cooperative and expandable knowledge-based systems that demonstrate a military planning capability in maneuver control and fire support. Maneuver control involves the planning of movements and actions of ground forces distributed across a battlefield. Fire support involves the planning of the assignment of distant fires (artillery, missiles, close air support) against enemy targets in support of ground force objectives.

The demonstration system envisioned to be built in this effort (which began in spring 1987) will incorporate three cooperating, loosely coupled knowledge-based subsystems that address maneuver-planning and fire-support decisions at the Army Corps level, and maneuver planning at the division level. These subsystems are referred to as MOVES(C), FIRES(C), and MOVES(D) respectively. Combined, these three systems represent three nodes in a conceptual FORCES network. The FORCES network is conceived as being a general architecture that allows distributed battle-management subsystems to be incorporated into a single, integrated battle-management system. Consequently, in addition to demonstrating functional planning capabilities in maneuver planning and fire support, this program will demonstrate a functional architecture that can gracefully incorporate other knowledge-based battle-management subsystems (viz., air defense, combat service support, and intelligence/electronic warfare) at all echelons in the Army (corps, division, regiment, brigade, etc.).

Each FORCES node will apply AI techniques to support multiple decision and analysis functions that occur at that node. For instance, for MOVES(C) corps-level maneuver planning, AI planning techniques may be used to support the generation of alternative COAs; expert systems may be used to support COA evaluation; planning, expert system and natural language processing techniques will be used to support preparation of detailed orders for lower-echelon units; expert systems will be used to support situation monitoring; and, finally, replanning may once again call on AI planning techniques.

Fire Support

Fire support is the application of artillery, surface-to-surface missiles, and close-in support resources against enemy targets in support of ground-force objectives. Fire support is a flexible resource that can be brought to bear against new objectives relatively fast. Consequently, fire-support planning is a continuous process that results in frequent updates to the allocation and distribution of this resource.

For purposes of this discussion, we can discriminate between fire control and fire planning. Fire control addresses the problem of selecting, aiming and firing upon actual targets. The selection criteria are generally well-defined and predefined (e.g., for the next two hours fire upon enemy tank regiments in area X), and are constantly being updated. Fire planning is the determination of these selection criteria. Fire planning requires an assessment of probable enemy activities in various regions, prediction of the types of targets that will appear, estimation of the impact and importance of these targets to friendly and enemy objectives, and finally, the selection of target classes and types that represent the high-payoff targets. Generally, fire-support planning is done in coordination with maneuver planning. Depending on the echelon, therefore, time horizons for fire planning can range from hours to days.

Regarding fire control, the Army is presently engaged in an effort to develop an Advanced Field Artillery Tactical Data System (AFATDS). AFATDS will be a distributed database system that will provide the fire support unit commander with the information necessary to select and fire at mobile enemy targets. Information on enemy units is principally in graphic form. In effect, AFATDS will be the MIS for fire-support commanders.

We know of only two efforts to provide advanced analytic support for fire-support decision making. Both of these efforts involve the development of a system that provides fire-support recommendations based on the data available about enemy targets. Both systems, therefore, are essentially of the DSS variety. They are described below.

TVA/ADF (Target Value Analysis/Allocation and Distribution of Fires)

In concert with their work on the Advanced Field Artillery Tactical Data System (AFATDS), Magnavox Corporation is internally supporting the development of a system to support the TVA/ADF decision process. TVA is the problem of identifying high-value targets; that is, those targets which have the highest relevance to the present mission of the ground forces (withdraw, hold present line of defense, break through enemy line of defense, etc.). Allocation is the determination of the assets (e.g., different types of artillery rounds) that should be allocated to each fire-support unit. Distribution is the determination of the enemy targets that the fire-support assets should be applied against. Unlike the description of the Marine Fire Support decision process provided by Slagle and Hamburger (1985) and discussed in the next section, fire support in the Army is largely a planning process. The final product of the TVA/ADF analysis process is a set of 'distribution rules' that are sent to individual fire support units. These rules provide instruction to the fire-support units as to which types of targets should be targeted under different conditions (e.g., from 1300 to 1600 target enemy artillery units in area X).

The TVA/ADF work is still in the early stages of prototype development. A variety of decision-support algorithms have been proposed for various elements of the TVA/ADF decision process, including techniques from artificial intelligence, decision analysis, and operations research. At present, however, the form of the final system is not fully defined.

The interesting element of the TVA/ADF work is that it has been initiated by a contractor directly involved in the development of an operational C^2 system, namely AFATDS. AFATDS is designed to be a distributed communication and database system in which each fire support unit will have a local computer terminal/computer that will provide a database of targets, target values, target locations, etc. The goal of the decision-aiding work at Magnavox is to enhance the utility of the AFATDS system to its users.

Battle

Battle (Slagle and Hamburger, 1985) is a decision aid designed to assist fire-support planning. As noted by Slagle and Hamburger, the immediate objective of Battle is to improve the existing MIFASS (Marine Integrated Fire and Air Support System) intended to "provide for the establishment of fire and air support centers to plan, integrate, direct, and coordinate the use of supporting arms."

Battle was developed at the Navy Center for Applied Research in Artificial Intelligence.

Battle generates recommendations for target-specific fire support plans by employing two separate analytic phases. Descriptions of these two phases, along with a summary of their user interface characteristics, are provided below.

Phase 1: Weapon/target effectiveness assessment. For a given fire-support problem, Battle starts the analytic process by evaluating the effectiveness of each possible target-weapon pairing. It does this through the application of relevant 'computation networks.' A computation network is similar to an inference network with the exception that the possible set of mathematical expressions for calculating node values is expanded to include more than just probability/relative likelihood assessments typically associated with inference networks. For instance, a simple CANREACH function can be included in the network to determine if a particular fire-support weapon, in its present location, can in fact reach the target being considered.

Battle applies computation networks to each possible target/weapon pair to generate an assessment of the effectiveness of that weapon against the respective target. The results of the repeated application of the networks are then stored in a central database of computational results. This database provides the input to the Phase II analysis.

Phase 2: Generate composite fire support plans. Once the effectiveness of alternative target/weapon pairings is assessed, Battle then attempts to find an 'optimum' distribution of resources against targets. Specifically, using user-defined target values, Battle attempts to find a distribution of fire-support resources that will maximize total target value destroyed.

Battle treats the optimization problem as a heuristic tree-search problem, where each node in the tree represents a choice of applying a particular weapon at a particular target at a particular time. Since the number of possible decision points is prohibitively large for realistic problem domains, a pruning algorithm is embedded in the search mechanism. In AI, search pruning algorithms are often based on simple equations for estimating the best that a particular search branch will be able to achieve. In Battle, the pruning algorithm compares a proposed change to a distribution plan against other distribution plans that have already been developed. If the estimated best that the new emerging plan can do is not as good as the previous plans, then that search branch is terminated.

One advantage of a tree-search approach to optimization is that the search process often quickly leads to a reasonable 'first pass' solution but then continues to search for progressively better solutions. As a result, the search process can be tailored to the time limitations of individual decision problems. In addition, Battle users are permitted to constrain the solution generated in a variety of ways (e.g., ignore certain units, allocate or prevent allocation of a specific weapon against a specific target, etc.). Imposing constraints on an optimization system employing tree-search procedures, such as Battle, does not significantly reduce run-time efficiency. These constraints are easily incorporated into the pruning mechanism that reflects search branches inconsistent with the user-defined constraints.

Battle is a good example of the application of expert-system technology to a battle-management decision process. The focus of a system such as Battle is on the repetitive applications of a relatively small knowledge base (the computation networks) against a problem involving a large space of options; that is, it provides a rapid and repetitive application of 'superficial' reasoning procedures.

Intelligence and Electronic Warfare

The term 'intelligence' refers to the collection, correlation, and analysis of information needed to support command decision making. Intelligence *collection* is the process of tasking sensors and other collectors, and recording the information they return. *Correlation* or *fusion*, is the process of translating bits and pieces of collected information into a single integrated picture of the present status of an area of concern. In a conventional battle, for instance, the product of *tactical fusion* is a 'snapshot of the battlefield.' Intelligence *analysis* involves the generation of higher-level interpretations of the fused information. For instance, it is the responsibility of a *tactical intelligence analyst* to predict which course of action a battlefield adversary may pursue.

Tactical Fusion

National defense establishments today possess an incredible array of sensor and other devices for collecting data about the status and activity of virtually any entity on a battlefield. These various devices collect many different types of data such as normal or infrared photographs, radar images, reports of electronic emissions, acoustic information, etc. Each type of data may indicate something about the entity observed, but not everything that needs to be known. One device may indicate where something is, but not what it is. Another may be informative about what it is, but not where it is or how big it is (e.g., regiment or division). A third may be indicative of size (e.g., large armored unit), but not much about type (e.g., tank vs. motorized rifle).

The problem of tactical fusion is to transform a continuous stream of literally thousands of collection reports into a list of military units and their locations that represents a single integrated picture of the present battlefield. This is a massive data-processing and interpretation problem that many believe can not effectively be done manually.

Over the last two decades, the services have been jointly pursuing the development of an automated system for performing tactical fusion. This program, called the Joint Tactical Fusion Program, is presently focused on the development of a tactical fusion center that would correlate data from diverse sources. In the Army, this center is referred to as the All Source Analysis System (ASAS).

The goal of ASAS is to correlate all sources of battlefield information to generate and disseminate a timely picture of the battlefield. This system will include both data-management and algorithmic support of the fusion process. Many of the inference algorithms to be embedded in ASAS will be based on a variety of advanced analytic technologies (e.g., AI). Consequently, from our perspective, many of the subsystems being developed for ASAS will function essentially as DSSs. By way of illustration, an example of this type of system is provided below.

AELASS (Automated Exploitation of the Large Area Surveillance Sensor). AELASS is a production-rule system, developed by PAR Government Systems Corporation, for identifying the activities of military units based on surveillance data that is provided from a variety of collection devices. The description of this prototype system is drawn from Dyer, Frantz, and Livingston (1983).

Problem Domain. The increasing mobility of military ground forces makes essential the rapid collection and exploitation of sensor data to track enemy positions and to assess their intent. Advanced sensor systems exist to collect data sufficient to meet this requirement. However, because of the quantity of data and the short amount of time available for analysis, computer support is required to correlate these data.

Many sensor systems possess two basic modes of operation: surveillance and tracking. The accurate tracking mode is used to determine specific target location and identification. Surveillance mode provides general information on levels of activity over large areas. Most systems for automated tactical fusion rely on the accurate data derived from tracking mode. But this limits the amount of terrain that can be covered. The AELASS system is oriented toward better exploitation of surveillance mode data. This greater exploitation includes detection of targets, maintenance of an activity-level history and estimates of enemy-activity level.

System Description. AELASS identification of high-level military activity is performed in two parts. The first part of the system handles routine manipulations of data, such as collection reports, and calculates averages of area activity levels over time. The output of this part of AELASS is the input to the second part of the system, which is the rule-based component. This second part of AELASS applies production rules to analyze measures of area movements to identify significant, high-level activities (e.g., motorized rifle division moving west). This second part is described below.

Figure 2 shows the architecture of the rule-base component of AELASS. The rule base contains the knowledge that the system uses for its analysis of indicators and activities. The rule base is implemented as a text file containing the rules which describe the conditions for identifying specific indicators and activities, and also the conditions for setting flags used by AELASS event-processing algorithms. For a rule base with no internal errors, the parser will produce an inference-net representation of the rules in the form of Pascal data structures that represent the relationships between the antecedent and consequent parts of the rules. These data structures provide for fast and efficient execution of rules, while the parser and rule base provide for easy modifications of the rules. The inference engine uses the inference-net representation of the rule base to drive the analysis of high-level activities. It determines which rule conditions are satisfied, and therefore which identifications or status flag changes should be performed as a result.

The rules in AELASS are based on military doctrine, and test alternative hypotheses about ground movements on the basis of their consistency with this doctrine. A simple notional example might be:

```
IF          high activity in rear area, and
            high activity newly detected, and
            other units not moving rearward

THEN        assert new unit has entered rear area.
```

This rule is consistent with a doctrine that does not withdraw individual units from the battle area for reconstitution. Consequently, if high activity is detected, it probably reflects a new unit in the area, rather than the withdrawal of a unit already in the area.

The interface table and status flags provide the means of communication between the inference engine and other AELASS algorithms. The interface table is a list of counts and flags that are set and adjusted by the event-processing algorithms. For example, flags indicating detection of certain types of emissions in various areas are stored in the interface table. Also stored are counts such as the number

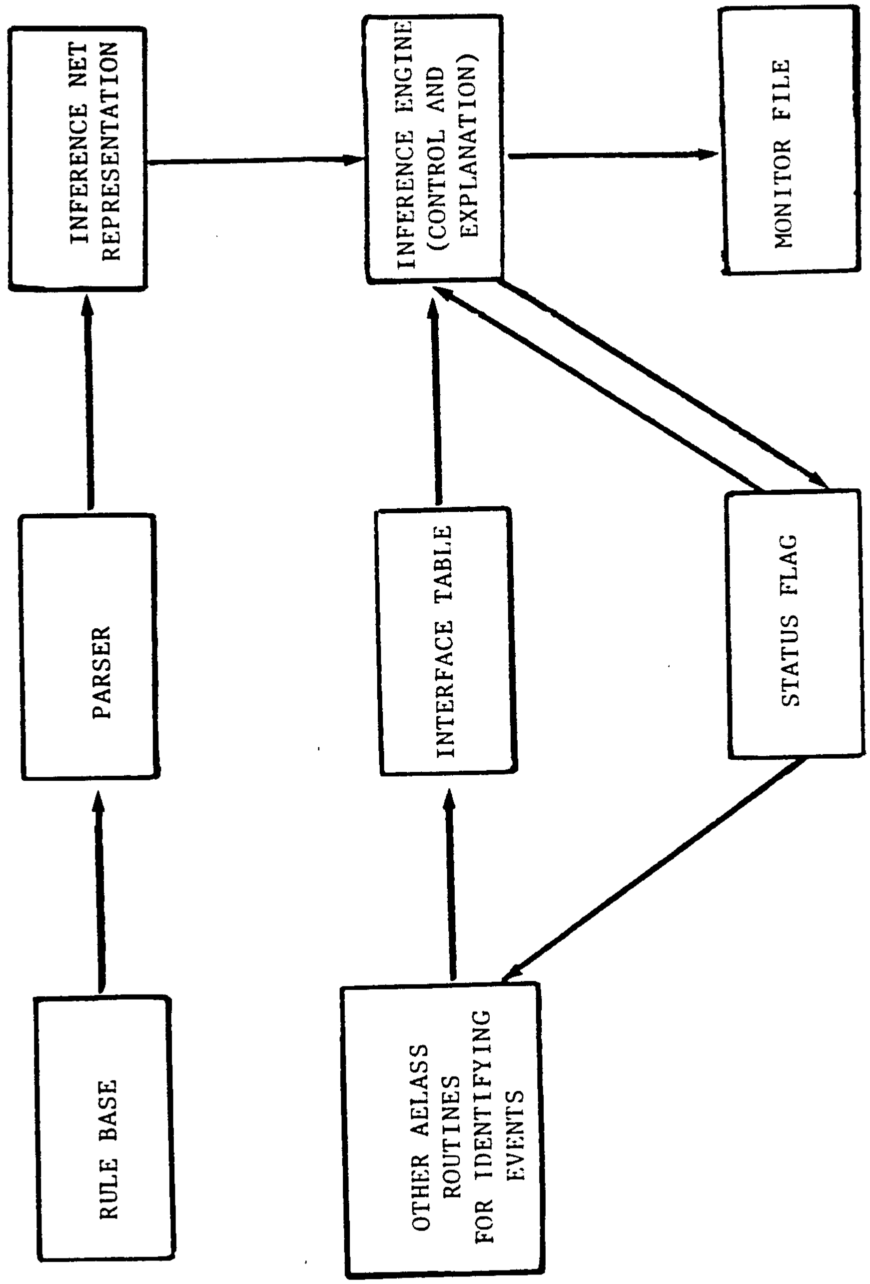

Figure 2. AELASS Rule-Based System Component Architecture.

of active units detected. Access to the interface table is depicted in the rule base as a function call which returns a true value if the test conditions represented by the function and its associated parameters are true.

Examples of status counts that are stored in the interface table include the number of active small units, the number of active large units, the number of areas where units stop, the number of areas with high-activity levels, etc. Fields that represent the detection of an event include identification of garrison area, communication in the forward area, active radar in the forward area, deployment of artillery in the forward area, deployment of engineering units, deployment of ground forces, meteorological data, and large units in the rear area.

Status flags indicate one of four possible states of activity: normal (the default), movement of forces to contact, preparation for movement to contact, and commitment of forces. The consequent part of the rules may instruct the inference engine to change the settings of the status flag to be used as evidence, or may itself be an antecedent condition for the identification of some activity or the formation of a new intermediate hypothesis. The inference engine manages the access to the interface table and status flags, as well as changing the status-flag setting when appropriate conditions in the rules are satisfied.

The output of the inference engine is a sequence of statements on the identifications or status changes identified by the rules. These statements are written to a monitor file which may be displayed to the user. In debug or explanation modes, the inference engine will also report the reason for each identification.

AELASS is a typical example of the type of AI systems that are being developed for ASAS. These systems are designed to perform automated analysis of the data available from various information sources, to recommend inferences about the location of enemy units.

The development of AELASS was supported by RADC as part of their overall program to develop advanced algorithms for tactical fusion. A number of other prototype systems have been developed with similar capabilities (e.gs., Pecora, 1984; Panda et al., 1984; Wilson et al., 1984; Drazovich, 1984; McCune et al., 1983; Kim et al., 1984; Hadly et al., 1984; Campen and Gordon, 1984; Taylor et al., 1984; Brown et al., 1982; and Bonasso, 1984).

Intelligence Analysis

Intelligence analysis involves a higher-level interpretation of correlated data to estimate intent and probable activities. In a tactical battlefield, for instance, intelligence analysis would be oriented toward such things as predicting enemy courses of action ("Are they going to attack in sector Y, and if so when?"). Performing this type of assessment is a complex problem that requires a broad knowledge base. The intelligence analyst performing this function is likely to use any of a variety of knowledge sources to make this type of assessment. These knowledge sources include:

- knowledge of enemy tactics, and the doctrinal employment of those tactics;
- knowledge of terrain, weather, and other physical characteristics of the environment;
- knowledge of enemy resources, systems, capabilities, and how they relate to the present environment (placement, mobility, status, etc.);
- knowledge of friendly resources, systems, and capabilities and how they relate to the present environment;
- knowledge of how the enemy may perceive friendly capabilities;
- knowledge of the broader political and economic environment that impacts or constrains enemy options (e.g., will not traverse neutral territory);
- knowledge of an enemy commander's tendencies (e.g., conservative).

As the above example illustrates, intelligence analysis is like many higher-level analysis and decision problems in that the problem solver must have a broad knowledge base to work from. This makes intelligence analysis a problematic application area for some decision-support system technologies. Expert system technology, for instance, is generally limited to domains where there is a well-defined and bounded knowledge base. This suggests that the application of this technology must be limited to carefully selected subproblems which can be well-bounded and well-defined in their knowledge requirements. For instance, expert-system techniques could effectively be used to assess the readiness and status of enemy units or perhaps evaluate the impact of weather and terrain conditions on projected enemy movements. An example of such an aid (AI/ENCOA) is described in the section titled <u>An Aid for Estimating Enemy Courses of Action</u>.

Although DSSs for automated intelligence analysis may be difficult to develop, decision aids to support the intelligence analyst's decision processes are another matter. Here the focus would be on supporting the analyst's inference and decision-making process, without necessarily performing an automated analysis of the data. An example of this type of aid is described in the section titled <u>BAUDI</u>.

<u>An Aid for Estimating Enemy Courses of Action</u>. AI/ENCOA is an example of a prototype, advanced-technology DSS designed to assist Army tactical intelligence analysts in evaluating alternative Enemy Courses of Action (COAs). AI/ENCOA combines the use of additive multiattribute utility (MAU) analysis for course-of-action evaluation with rule-based procedures for assigning parameter values (scores and weights) to the MAU model. The description of this system is taken from Lehner et al. (1984; 1985).

Problem Domain. At the Army division level, one of the most important intelligence analyses to perform is that of predicting whether or not the enemy forces opposing that division are going to attack. AI/ENCOA attempts to assess, for a friendly division sector, whether the opposing forces are going to engage in a primary attack, secondary attack, hold in a defensive posture, or withdraw. Furthermore, once it is determined that the opposing forces are going to engage in some type of attack, AI/ENCOA applies a further analysis to determine likely primary and secondary avenues of approach (AOAs).

System Description. Functionally, AI/ENCOA is composed of two parts: a generic software package that implements a combined AI/MAU architecture, and two rule bases for analyzing different kinds of enemy activity. Each of these is described below.

Conceptually, the AI/MAU software has three interacting components: (1) an MAU model and analysis capability; (2) a user interface system, called the Attribute Manager, that permits users to characterize the decision situation facing them, and (3) a set of composition or production rules that translate the description of the situation into appropriate scores and weights in the MAU model.

An MAU model is a type of decision-analysis model that is composed of a strictly hierarchical set of evaluation factors. MAU models select among alternative options by comparing each option on these evaluation factors. Each factor in the hierarchy is given an importance weight, and each option is scored relative to other options on the terminal factors.

The role of the attribute manager is to query the user as to the nature of the decision situation. It asks the user a series of questions about the specific problem the user is addressing. Each question corresponds to an attribute in a predefined attribute list. User answers to the questions set the value of each attribute in the general attribute list. Users also have the option to select and answer only those few questions addressing specific, minimal changes in repetitive decision situations, thereby permitting them to quickly modify the status of the attribute list.

The role of the parameter assignment rules is to translate the information about the decision situation, encoded in the attribute list, into scores and weights in the MAU model. This rule base will be decomposed into independent rule sets that correspond to the nodes in the MAU hierarchy. For each node in the hierarchy, there is a set of composition rules that determines the value of the parameters associated with that node. The preconditions in each rule correspond to one or more attributes in the attribute list. The action resulting from each rule is the assignment or functional adjustment of the parameter value of the associated node in the hierarchy.

AI/ENCOA presently has available two 'knowledge bases'. As noted above, each knowledge base is composed of an MAU model for evaluating alternative options, and a rule base for assigning scores and weights to the MAU model. The MAU models are similar to the one found in TACPLAN. The first knowledge base attempts to assess which COA the enemy is likely to pursue, while the second identifies likely AOA's under the assumption that an attack is imminent.

This general approach to building an MAU-based expert system has two distinct advantages. First, the use of the attribute manager and parameter assignment rules makes it possible to interface with users in terms and references with which they are familiar. In this regard, the user interface is very similar to that found in expert systems that do not contain a normative decision model. Second, as with other rule-based systems, this aid can be incrementally improved by simply adding, deleting, or modifying rules. This makes it possible to continually improve the aid's knowledge base, encoded as a combined normative MAU model and rule base, over time.

BAUDI (Bayesian Aid for Updating Intelligence Information). Adelman et al. (1982) describe a decision aid (later called BAUDI) to support the process of revising one's estimate of the probability of a hypothesis given new information. As shown in Figure 3, this aid required a user to specify an initial set of hypotheses, initial probabilities for those hypotheses, and as each new item of information was received, the probability of receiving the information item given each hypothesis. Based on these inputs, the decision aid would calculate posterior

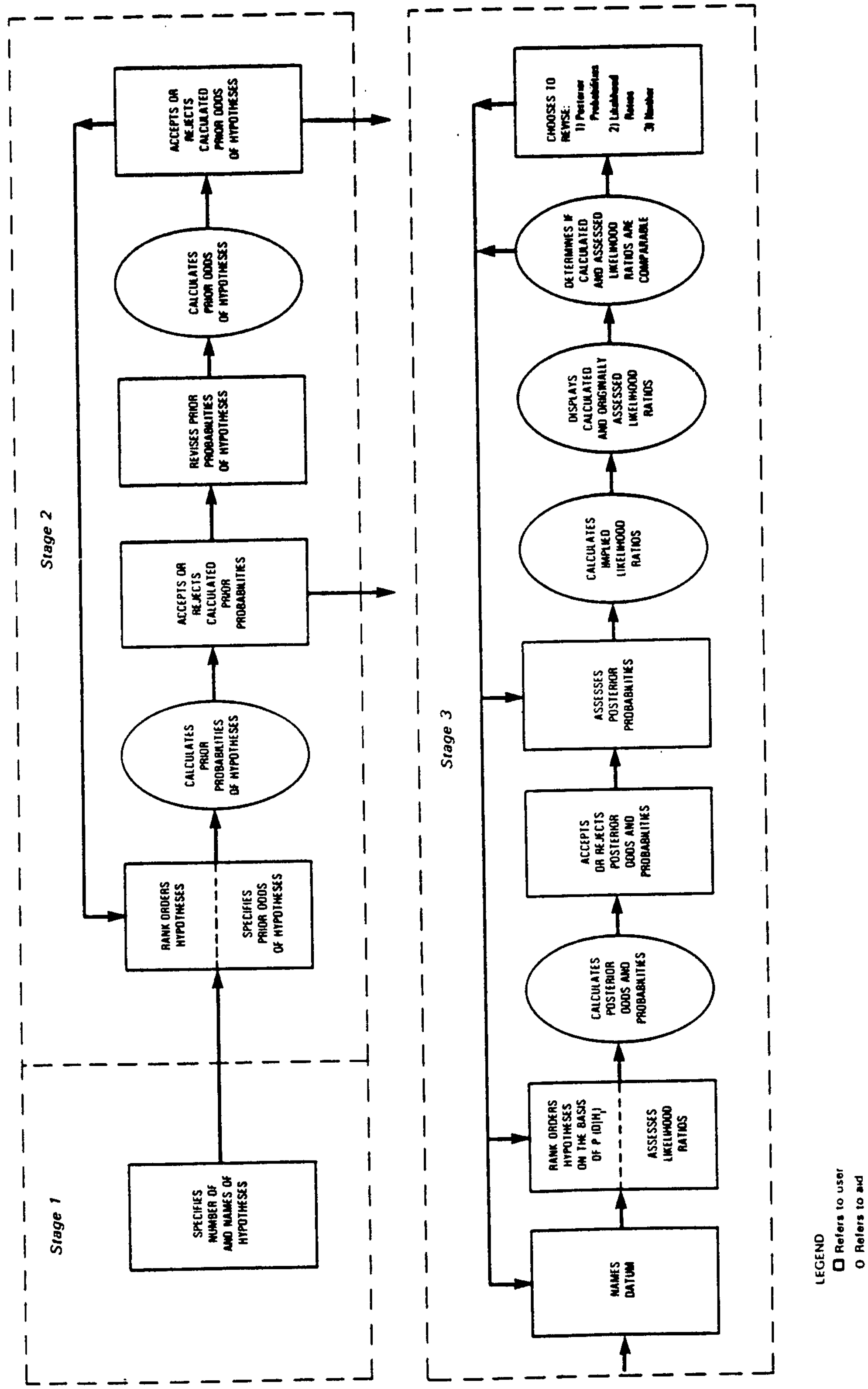

Figure 3. Flowchart describing BAUDI's three distinct stages.

probabilities for each hypothesis. The aid was designed such that the user could review and revise any of the user- or machine-generated probability estimates at various points.

Adelman et al. (1982) describe an experiment in which intelligence analysts used this aid to predict which Avenue of Approach an enemy was going to use for its main attack. The results of this experiment were generally positive in that intelligence analysts using the aid were better able to discriminate the relative likelihood of alternative hypotheses, and were more consistent with the Bayesian norm, than analysts not using the aid.

The focus of this work was on evaluating the utility of Bayesian decision aids, and the development of user interface procedures to enhance their utility. The principal interest of this type of aid is enhanced decision processing.

Air Defense

Forward Area Air Defense (FAAD) is a key area of concern in the defense of Army ground forces. The Army is actively pursuing the development of FAAD Systems (FAADS) which would include a C^2 system for air defense.

Until recently, much of the Army's efforts in FAAD have focused on the development of the Sgt. York Division air defense gun. This program, however, did not meet expectations and was cancelled in August of 1985. To date, a replacement(s) for this weapon has not been selected. Consequently, requirements of the air defense system component of an automated Army C^2I system are not fully defined. The Army is, however, actively pursuing R&D research in this area. Once a system is fielded, it is likely that DSS application programs will be developed to further support air-defense decision making.

At present, we know of no active work in the development of decision aids for ground-based air defense. DSC, however, is presently involved in a research effort to define criteria for allocating functions to humans and computers for air-defense decision aids or decision-support systems. In particular, this effort is attempting to identify the types of decision-support options most useful to air-defense decision makers.

Combat Service Support

The goal of combat service support (CSS) is to maintain and support weapon systems and their operators. In effect, this means the logistics support to operate and maintain fielded weapons.

As with the other elements of the Army C^2 system, the Army is developing distributed database/information systems to support CSS decision making. This system will be composed of more than 10,000 microcomputer systems called the Tactical Army Combat Service Support Computer System (TACCS). Combined, these TACCS will provide a distributed logistics supply database and management system used principally by unit clerks and supply specialists.

At present, we do not know of any advanced analytic software to be embedded in the TACCS. However, this seems a natural area for algorithmic analysis of present and projected logistic requirements, and would seem a natural area for future DSS development.

It is not clear at this point whether decision aids to support logistics decision processes would be appropriate. We know of no work in this area.

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